(12) **United States Patent**
Wong et al.

(10) **Patent No.: US 9,056,754 B2**
(45) **Date of Patent: Jun. 16, 2015**

(54) **METHOD AND APPARATUS FOR USING PRE-POSITIONED OBJECTS TO LOCALIZE AN INDUSTRIAL VEHICLE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **13/672,391**

(22) Filed: **Nov. 8, 2012**

(65) **Prior Publication Data**

US 2014/0074342 A1 Mar. 13, 2014

Related U.S. Application Data

(63) Continuation of application No. PCT/US2012/054062, filed on Sep. 7, 2012, which is a continuation of application No. 13/227,165, filed on Sep. 7, 2011, now abandoned.

(51) **Int. Cl.**
G05D 1/00 (2006.01)
B66F 9/075 (2006.01)
G05D 1/02 (2006.01)

(52) **U.S. Cl.**
CPC ***B66F 9/0755*** (2013.01); ***G05D 1/021*** (2013.01); ***G05D 1/0274*** (2013.01); *G05D 2201/0216* (2013.01)

(58) **Field of Classification Search**
CPC G05D 2201/0216; G05D 1/0234; G05D 1/0274; G05D 1/0246; G05D 1/024; G01S 5/16; G01S 5/163; G01S 17/06; G01S 17/48; G01S 13/74; G01C 21/16; G01C 21/165; G01C 21/206; G01C 21/26
USPC 701/28, 23, 434, 2, 25, 408, 457, 500; 340/995.2, 10.1, 10.6, 572.1, 901, 988, 340/990; 700/253, 56, 214, 215, 225
See application file for complete search history.

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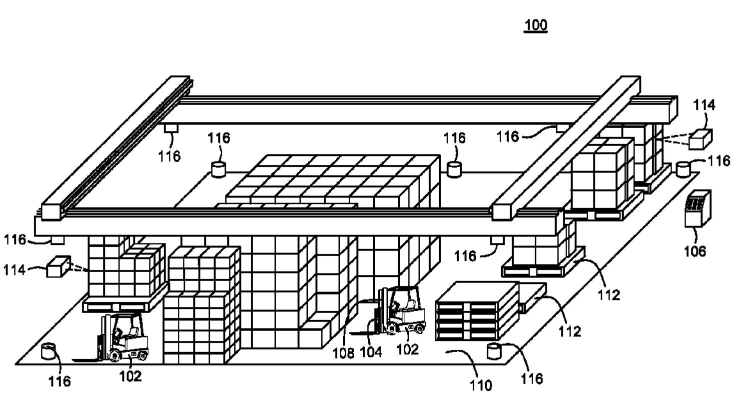
(57) **ABSTRACT**

According to one embodiment of the present disclosure, a method of using dynamically placed pre-positioned objects as landmarks to operate an industrial vehicle is provided. The method comprises (i) transporting an object along a path within the physical environment and placing the object at a location within the physical environment such that the placed object becomes a dynamically placed pre-positioned object in the physical environment; (ii) updating a map of the physical environment by adding placed object data representing the dynamically placed pre-positioned object to the map of the physical environment to create updated map data such that the placed object, when added to the map, serves as a landmark with observable features and can be used in the navigation of an industrial vehicle with access to the updated map data; (iii) storing the updated map data on a mobile computer attached to the industrial vehicle or on a central computer coupled to the industrial vehicle via a network; and (iv) operating the industrial vehicle based on a navigational position determined from sensor data and the updated map data by navigating the industrial vehicle along a path within the physical environment.

19 Claims, 6 Drawing Sheets



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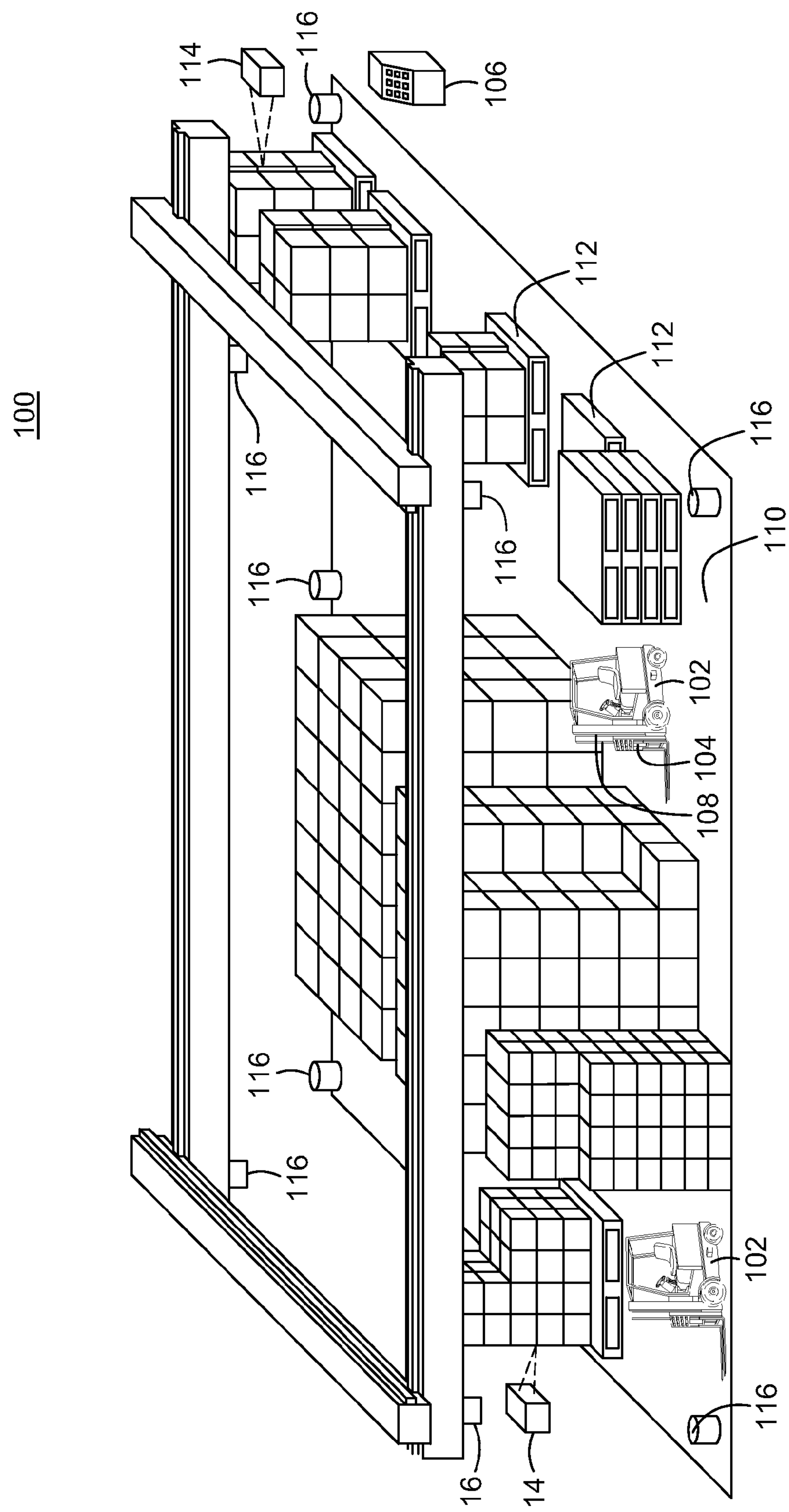
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FIG. 1

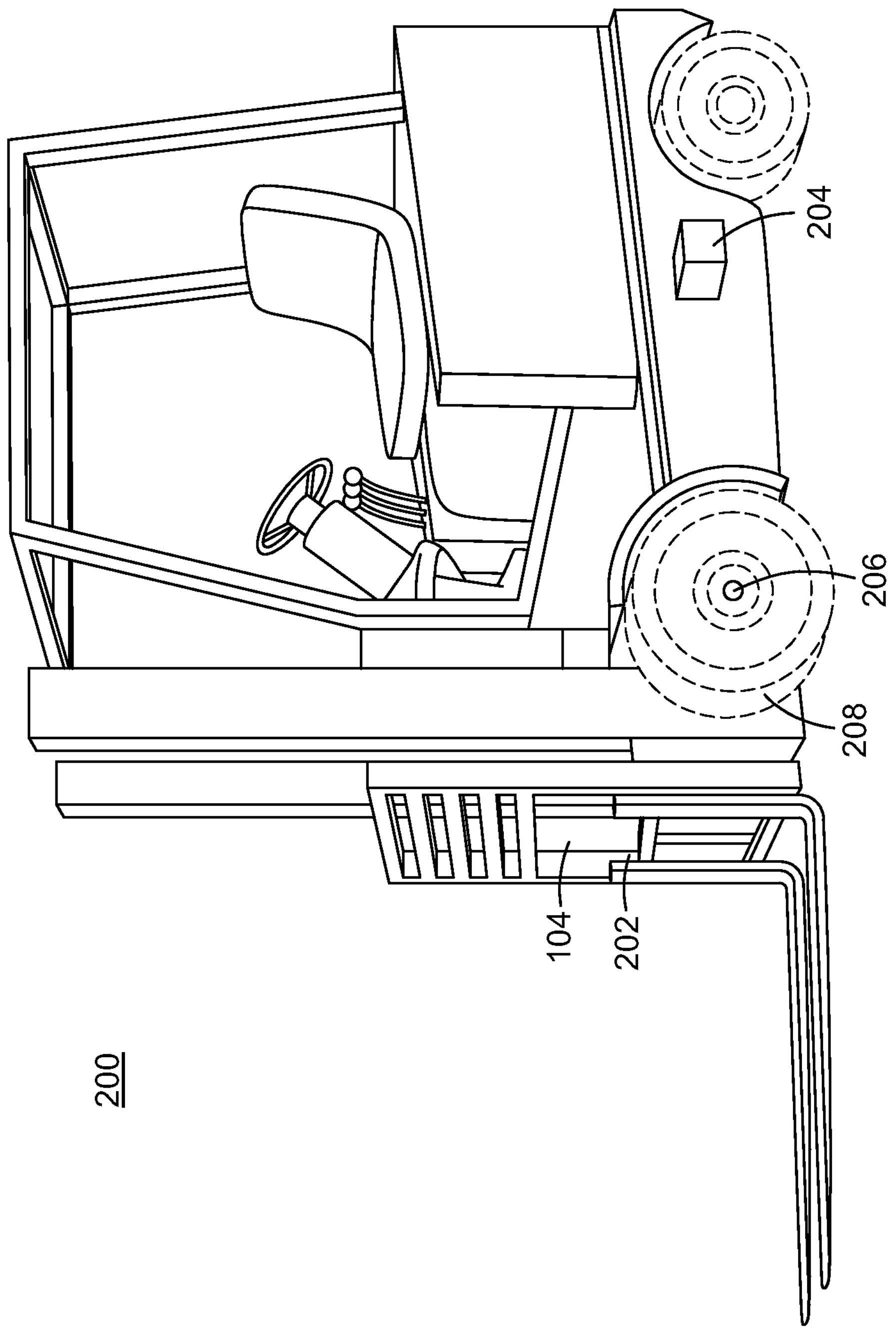
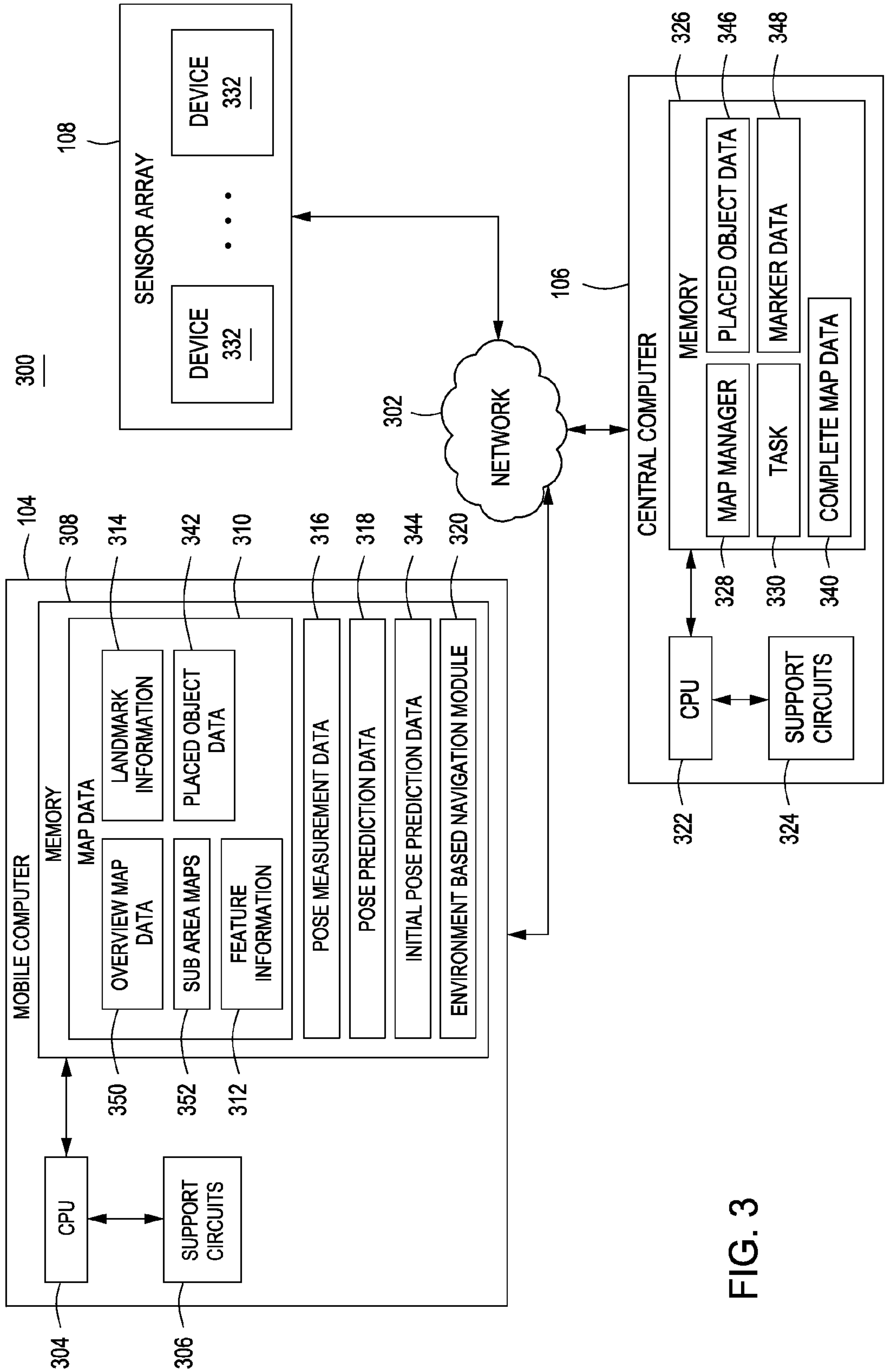


FIG. 2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LANDMARK INFORMATION
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SUB AREA MAPS
352
PLACED OBJECT DATA
342
FEATURE INFORMATION
312
POSE MEASUREMENT DATA
316
POSE PREDICTION DATA
318
INITIAL POSE PREDICTION DATA
344
ENVIRONMENT BASED NAVIGATION MODULE
320
SENSOR ARRAY
108
DEVICE
332
DEVICE
332
NETWORK
302
CENTRAL COMPUTER
106
CPU
322
SUPPORT CIRCUITS
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MEMORY
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TASK
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PLACED OBJECT DATA
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MARKER DATA
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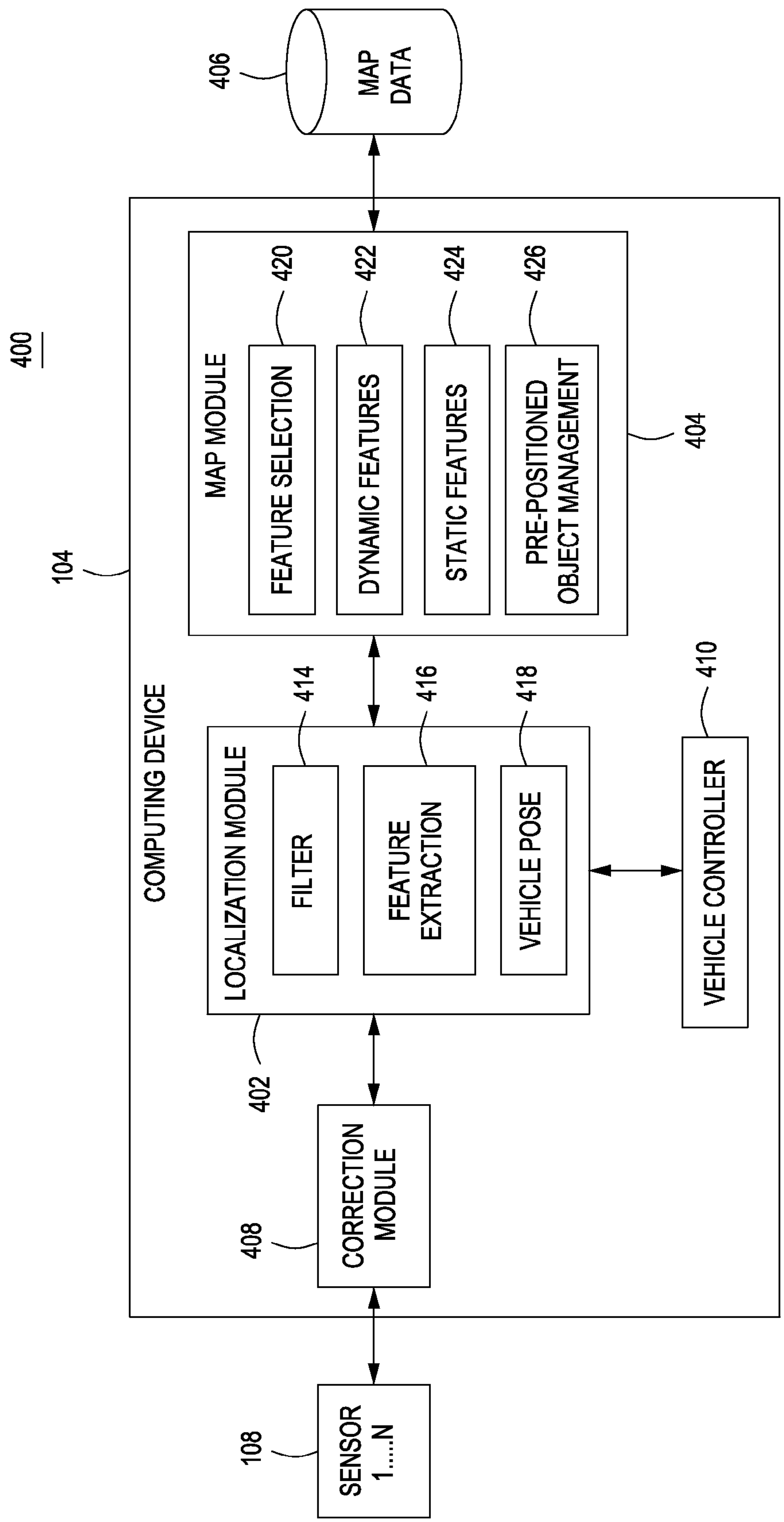
FIG. 3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MAP MODULE
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STATIC FEATURES
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PRE-POSITIONED OBJECT MANAGEMENT
426
404
LOCALIZATION MODULE
FILTER
414
FEATURE EXTRACTION
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418
402
VEHICLE CONTROLLER
410
CORRECTION MODULE
408
SENSOR 1....N
108

FIG. 4

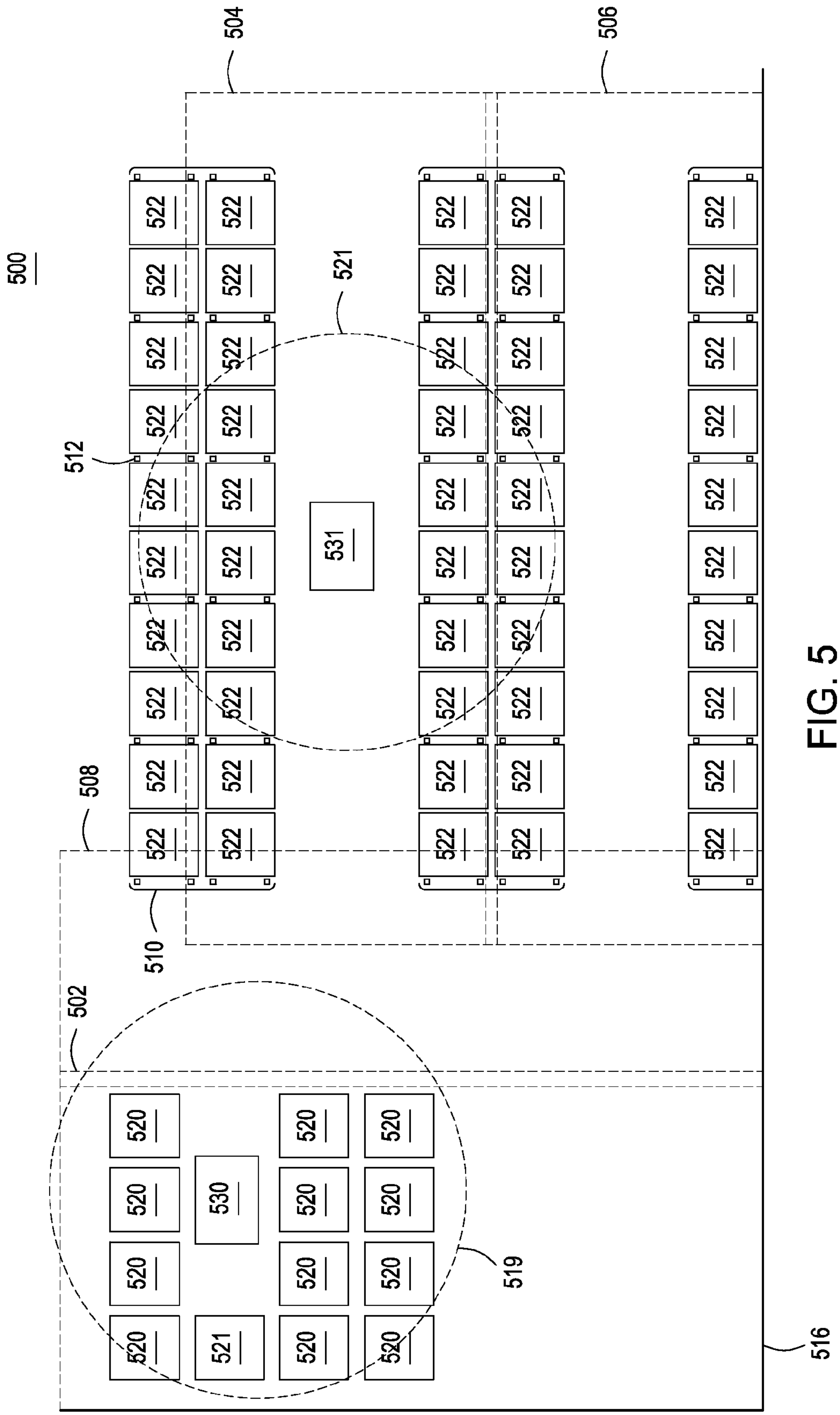
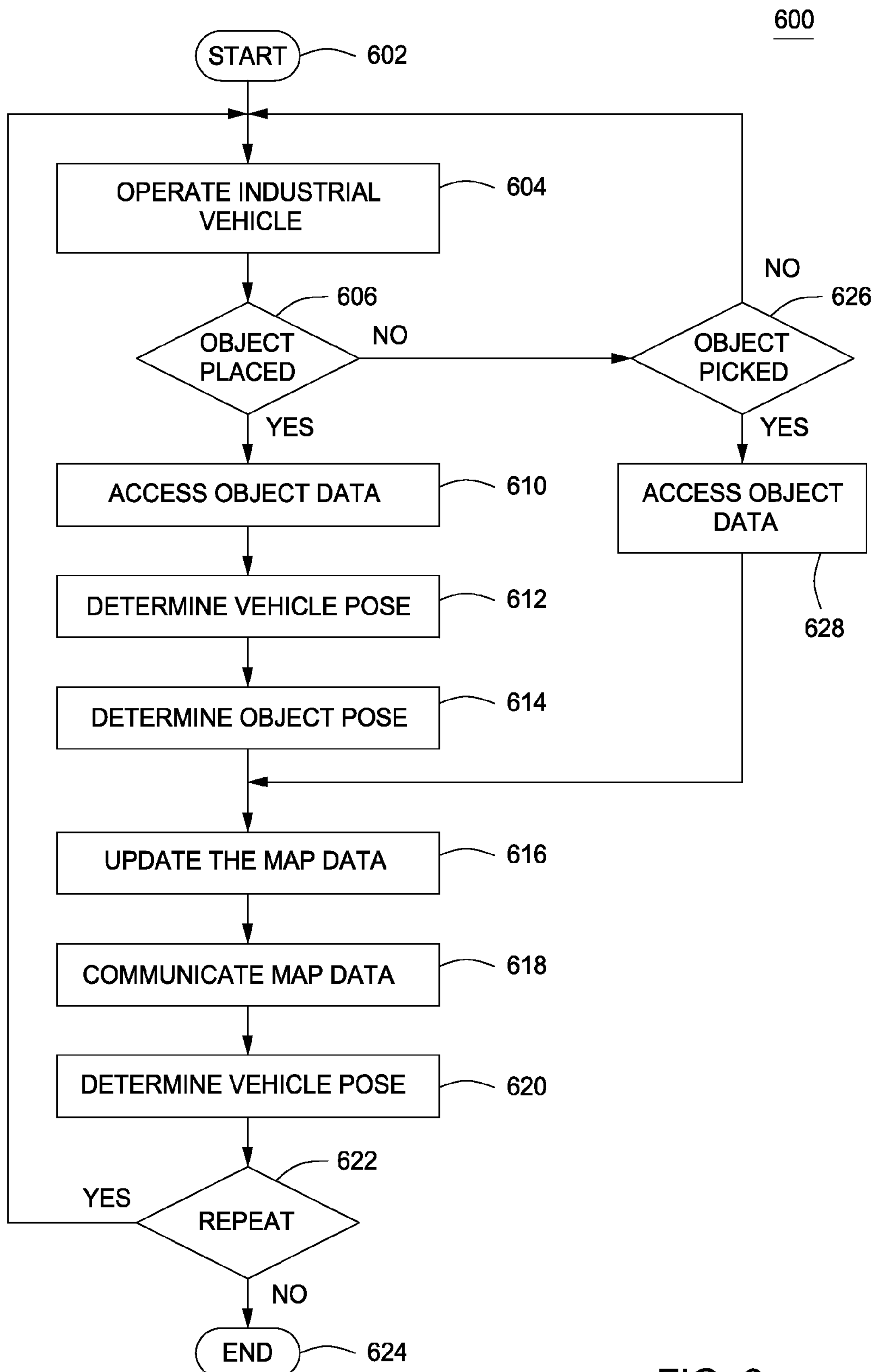


FIG. 5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OPERATE INDUSTRIAL VEHICLE
604
606
OBJECT PLACED
NO
YES
626
OBJECT PICKED
NO
YES
ACCESS OBJECT DATA
610
ACCESS OBJECT DATA
628
DETERMINE VEHICLE POSE
612
DETERMINE OBJECT POSE
614
UPDATE THE MAP DATA
616
COMMUNICATE MAP DATA
618
DETERMINE VEHICLE POSE
620
622
REPEAT
YES
NO
END
624

FIG. 6

METHOD AND APPARATUS FOR USING PRE-POSITIONED OBJECTS TO LOCALIZE AN INDUSTRIAL VEHICLE

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is filed under 35 U.S.C. 111(a) as a continuation of International Patent Application No. PCT/US2012/054062, filed Sep. 7, 2012, which international application designates the United States and claims priority to U.S. patent application Ser. No. 13/227,165, filed Sep. 7, 2011.

BACKGROUND

1. Technical Field

Embodiments of the present invention generally relate to industrial vehicle navigation systems and, more particularly, to a method and apparatus for using pre-positioned objects to localize an industrial vehicle.

2. Description of the Related Art

Entities regularly operate numerous facilities in order to meet supply and/or demand goals. For example, small to large corporations, government organizations and/or the like employ a variety of logistics management and inventory management paradigms to move objects (e.g., raw materials, goods, machines and/or the like) into a variety of physical environments (e.g., warehouses, cold rooms, factories, plants, stores and/or the like). A multinational company may build warehouses in one country to store raw materials for manufacture into goods, which are housed in a warehouse in another country for distribution into local retail markets. The warehouses must be well-organized and use floor space efficiently in order to maintain and/or improve production and sales. If raw materials are not transported to the factory at an optimal rate, fewer goods are manufactured. As a result, revenue is not generated for the unmanufactured goods to counterbalance the costs of the raw materials.

Unfortunately, physical environments, such as warehouses, have several limitations that prevent timely completion of various tasks. Warehouses and other shared use spaces, for instance, must be safe for a human work force. Some employees operate heavy machinery and industrial vehicles, such as forklifts, which have the potential to cause severe or deadly injury. Nonetheless, human beings are required to use the industrial vehicles to complete tasks, which include object handling tasks, such as moving pallets of goods to different locations within a warehouse. Most warehouses employ a large number of forklift drivers and forklifts to move objects. In order to increase productivity, these warehouses simply add more forklifts and forklift drivers.

Some warehouses utilize equipment for automating these tasks. For example, some warehouses employ automated industrial vehicles, such as automated forklifts, to carry objects on paths and then unload these objects onto designated locations. Many such warehouses offer few natural landmarks from which an automated vehicle can derive an accurate position and few have available locations on which navigational markers or beacons may be affixed. When navigating an automated industrial vehicle, it is imperative that vehicle pose computations are accurate. A vehicle pose in this context means its position and heading information, generally a pose refers to a position of an object in space with a coordinate frame having orthogonal axes of known origin and the rotations about each of those axes or a subset of such positions and rotations. If the industrial vehicle cannot determine a current pose in physical space, the industrial vehicle is unable to execute tasks. Thus automated vehicles typically employ an internal map or representation of the physical environment including the position of some navigational landmark references from which the vehicle pose may be calculated.

While using fixed infrastructure landmarks as a basis for localization or as a location to mount landmark beacons is known, using substantially pre-positioned objects or pallets as landmarks to facilitate navigation is not known. Therefore, there is a need in the art for a method and apparatus for localizing an automated industrial vehicle using dynamically placed pre-positioned objects as the majority of the landmark references.

SUMMARY

Various embodiments of the present disclosure generally comprise methods and apparatuses for using at least one movable, pre-positioned object as a landmark to localize an industrial vehicle are described. The method includes placing at least one movable, pre-positioned object within a physical environment, adding the pre-positioned object as a landmark to a map, associating observable features with the landmark from a model of the object and determining an industrial vehicle pose relative to the movable, pre-positioned object.

More specifically, according to one embodiment of the present disclosure, a method of using dynamically placed pre-positioned objects as landmarks to operate an industrial vehicle is provided. The method comprises (i) transporting an object along a path within the physical environment and placing the object at a location within the physical environment such that the placed object becomes a dynamically placed pre-positioned object in the physical environment; (ii) updating a map of the physical environment by adding placed object data representing the dynamically placed pre-positioned object to the map of the physical environment to create updated map data such that the placed object, when added to the map, serves as a landmark with observable features and can be used in the navigation of an industrial vehicle with access to the updated map data; (iii) storing the updated map data on a mobile computer attached to the industrial vehicle or on a central computer coupled to the industrial vehicle via a network; and (iv) operating the industrial vehicle based on a navigational position determined from sensor data and the updated map data by navigating the industrial vehicle along a path within the physical environment.

The pose of the dynamically placed pre-positioned object may be determined based at least in part on (i) pose prediction data stored on a central computer or a mobile computer coupled to the industrial vehicle and (ii) a location of the placed object relative to a lift carriage of the industrial vehicle. The determined pose may be used to create the updated map data and the industrial vehicle may be operated based on a navigational position that is determined by updated map data including the determined pose.

Landmarks can be created based on the placed object data and the placed object data may comprise features from the placed object, a landmark pose representing the location at which the object was placed, and/or an object pose uncertainty from the pose prediction data.

It is contemplated that a placed object may comprise a unique identifier and that a sensor on the industrial vehicle can be used to sense the unique identifier. In which case it may be advantageous to store placed object data on the central computer or the mobile computer with data representing the unique identifier.

Object pose prediction data can also be stored on the mobile computer or the central computer and the industrial vehicle may comprise a sensor for determining the location of an object to be placed relative to a lift carriage of the industrial vehicle. In which case, the pose of a placed object can be determined from the pose prediction data and the location of the object relative to the lift carriage of the industrial vehicle.

In some instances, the industrial vehicle will transition from an unpowered state to a powered state where current vehicle pose is unknown. In which case, the industrial vehicle can be subsequently operated by determining current vehicle pose from the updated map data and navigating the industrial vehicle along the path within the physical environment.

A dynamically placed pre-positioned object may comprise a known geometry. The known geometry may be defined as placed object model data that describes a set of feature information for the dynamically placed pre-positioned object and the industrial vehicle may be operated based on vehicle localization using the placed object model data. In some cases, the dynamically placed pre-positioned object comprises a pallet and items located on the pallet and the updated map data comprises a model of the pallet and the items located on the pallet. In other cases, the updated map data comprises invisible dynamic objects generated from slot locations according to parametric data derived from warehouse rack dimensions or according to a site defined storage rule for block storage areas and the method comprises updating the map to make the invisible object visible. In still further cases, placed object data representing dynamically placed pre-positioned objects serves as a landmark comprising features that are observable from more than one side of the landmark. Typically, placed object data is at least partially derived from a sensor attached to the industrial vehicle and the corresponding sensor data from which the navigational position is determined may comprise image data, laser range data, ultrasonic range data, pressure transducer data, encoder data, or combinations thereof.

In many cases, the placed object data forms a majority of landmarks comprised in the updated map data and the current vehicle pose is often determined by referring to landmark data predominantly comprising placed object data. In some embodiments, the current vehicle pose is determined by referring to landmark data consisting entirely of placed object data.

It is contemplated that the step of operating the industrial vehicle based on the navigational position determined from the sensor data and the updated map data comprises one or more automated operations executed with the assistance of a central computer or a mobile computer attached to the industrial vehicle. In which case, it is also contemplated that the automated operations are selected from a vehicle navigating operation, a vehicle status alert display, or combinations thereof.

According to another embodiment of the present disclosure, a computer is attached to the industrial vehicle or coupled to the industrial vehicle via a network. The computer comprises a navigation module for operating the industrial vehicle based on a navigational position determined from sensor data and the updated map data. The computer enables the use of dynamically placed pre-positioned objects as landmarks to operate an industrial vehicle.

The aforementioned vehicle operation may comprise one or more manual operations executed by a driver residing on the industrial vehicle, one or more automated operations executed with the assistance of a central computer or a mobile computer attached to the industrial vehicle, or combinations thereof. For example, and not by way of limitation, it is contemplated that vehicle operation may comprise vehicle navigation, which may include positioning, steering, speed control, load engagement, lifting, etc. Additionally, and not by way of limitation, it is contemplated that vehicle operation may include the display or other execution of a vehicle status alert.

BRIEF DESCRIPTION OF THE DRAWINGS

So that the manner in which the above recited features of the present invention can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

FIG. **1** is a perspective view of a physical environment comprising various embodiments of the present disclosure;

FIG. **2** illustrates a perspective view of the forklift for navigating a physical environment to perform various tasks according to one or more embodiments;

FIG. **3** is a structural block diagram of a system for using dynamically placed pre-positioned objects as landmarks to localize an industrial vehicle according to one or more embodiments;

FIG. **4** is a functional block diagram of a system for providing accurate localization for an industrial vehicle according to one or more embodiments;

FIG. **5** is a schematic illustration of a map for a physical environment comprising dynamically placed pre-positioned objects as landmarks according to one or more embodiments; and

FIG. **6** is a flow diagram of a method of designating a pre-positioned object as a unique landmark for facilitating localization according to one or more embodiments.

DETAILED DESCRIPTION

FIG. **1** illustrates a schematic, perspective view of a physical environment **100** comprising one or more embodiments of the present invention.

In some embodiments, the physical environment **100** includes a vehicle **102** that is coupled to a mobile computer **104**, a central computer **106** as well as a sensor array **108**. The sensor array **108** includes a plurality of devices for analyzing various objects within the physical environment **100** and transmitting data (for example, image data, video data, range map data, three-dimensional graph data and/or the like) to the mobile computer **104** and/or the central computer **106**, as explained further below. The sensor array **108** includes various types of sensors, such as encoders, ultrasonic range finders, laser range finders, pressure transducers and/or the like.

The physical environment **100** further includes a floor **110** supporting a plurality of objects. The plurality of objects include a plurality of pallets **112**, a plurality of units **114** and/or the like as explained further below. The physical environment **100** also includes various obstructions (not pictured) to the proper operation of the vehicle **102**. Some of the plurality of objects may constitute as obstructions along various paths (e.g., pre-programmed or dynamically computed routes) if such objects disrupt task completion.

The physical environment **100** also includes a plurality of markers **116**. The plurality of markers **116** are illustrated as objects attached to a floor and/or ceiling. In some embodiments, the plurality of markers **116** are landmark beacons, some of which may be unique or provide a unique configuration that facilitate vehicle localization by an environment based navigation as explained further below. The plurality of markers **116** as well as other objects around the physical environment **100** form environment landmarks with observable features by at least one sensor such as from the sensor array **108**. The mobile computer **104** extracts the environment features and determines an accurate, current vehicle pose.

The physical environment **100** may include a warehouse or cold store for housing the plurality of units **114** in preparation for future transportation. Warehouses may include loading docks to load and unload the plurality of units from commercial vehicles, railways, airports and/or seaports. The plurality of units **114** generally includes various goods, products and/or raw materials and/or the like. For example, the plurality of units **114** may be consumer goods that are placed on ISO standard pallets and loaded into pallet racks or block stacked by forklifts to be distributed to retail stores. The industrial vehicle **102** facilitates such a distribution by moving the consumer goods to designated locations where commercial vehicles (e.g., trucks) load and subsequently deliver the consumer goods to one or more target destinations.

According to one or more embodiments, the vehicle **102** may be an automated guided vehicle (AGV), such as an automated forklift, which is configured to handle and/or move the plurality of units **114** about the floor **110**. The vehicle **102** utilizes one or more lifting elements, such as forks, to lift one or more units **114** and then, transport these units **114** along a path to be placed at a designated location. Alternatively, the one or more units **114** may be arranged on a pallet **112** of which the vehicle **102** lifts and moves to the designated location.

Each of the plurality of pallets **112** is a transport structure that supports goods in a stable fashion while being lifted by the vehicle **102** and/or another jacking device (e.g., a pallet jack and/or a front loader). The pallet **112** is the structural foundation of an object load and permits handling and storage efficiencies. One or more parts of the plurality of pallets **112** may be utilized within a rack system (not pictured). Within one type rack system, gravity rollers or tracks allow one or more units **114** on one or more pallets **112** to flow to the front. The one or more pallets **112** move forward until slowed or stopped by a retarding device, a physical stop or another pallet **112**. Other types of rack systems support pallets by interlocking the pallets with horizontal shelves providing additional stability. With this type of racking, the lowest pallet is often placed on the floor with the pallet face in front of the rack uprights thus significantly obscuring the rack uprights and rendering them unavailable as landmark references.

In many instances some areas of the physical environment **100** are designated as block storage areas, here pallets **112** are placed on the floor with other pallets stacked on top. Such block storage areas are arranged to be many pallets wide and many pallets deep and have pallets stacked high so that there are no natural landmarks or beacons **116** visible to an industrial vehicle that is deep in the row of pallets.

In some embodiments, the mobile computer **104** and the central computer **106** are computing devices that control the vehicle **102** and perform various tasks within the physical environment **100**. The mobile computer **104** is adapted to couple with the vehicle **102** as illustrated. The mobile computer **104** may also receive and aggregate data (e.g., laser scanner data, image data and/or any other related sensor data) that is transmitted by the sensor array **108**. Various software modules within the mobile computer **104** control operation of the vehicle **102** as explained further below.

Embodiments of this invention may make use of the location of pallets **112** placed on the physical environment **100** as landmarks to facilitate the accurate navigation of the industrial vehicle **102**. In some embodiments the mobile computer **104** records the locations of pallets **112** placed in the environment and updates a map of the facility with the location of these pallets. As further explained below the mobile computer **104** uses a model of the pallet **112** and items **114** located on the pallet to create a landmark with the sensor observable navigational features of the combined load. The industrial vehicle **102** develops a position by observing the navigational features from the sensor array **108** while carrying out one or more tasks. The observed features are compared with known mapped static and/or dynamic features in a filter to determine an estimate of current vehicle pose. It should be recognized that there is a significant difference in recognizing the pallets **112** as obstacles to navigation and using the placed pallets as navigational landmarks for the accurate localization of an industrial vehicle **102** such that other pallets may be picked or placed safety in the positions required by one or more tasks.

As explained further below, the mobile computer **104** defines one or more sub-areas within the physical environment **100** for facilitating localization. The physical environment may be segmented into a plurality of sub-areas with corresponding map data stored in the plurality of sub-area maps to limit the number of landmarks to be considered for localization. Sub-area map generation is described in U.S. patent application Ser. No. 13/159,501, filed Jun. 14, 2011. The sub-area maps enhanced with pre-positioned objects may be shared between a plurality of industrial vehicles. Pre-positioned objects are objects, such as pallets and loads with known representative geometric models, which may be positioned on a map by an industrial vehicle and subsequently used as a localization reference. The sharing of map data between industrial vehicles is described in U.S. patent application Ser. No. 13/159,500, filed Jun. 14, 2011. It is appreciated that sub-area maps may comprise portions of the facility **100** in which dynamically placed pre-positioned product may be substantially the only visible landmark from which an industrial vehicle may obtain a localization reference.

Unlike fixed infrastructure, the location of pre-positioned objects is not exact but is calculated by the automated industrial vehicle that placed the object. Thus, the pose of the dynamically placed pre-positioned object may be subject to error arising from a variety of factors. The factors include, but are not limited to, uncertainty in the location of the vehicle when it places the product, uncertainty in the location of the object on the forks of the vehicle, movement of the object while it is being placed, movement of the object when other pallets **112** containing product are stacked on the object, and movement occurring from incidental contact with machinery, and the like. Thus, the mobile computer **104** must model the location of the pre-positioned object the features associated with the object and the uncertainty of the position of the object. These errors are in addition to the uncertainty associated with a sensor observation measurement of the object, thus pre-positioned objects are landmarks on the map requiring processing by the mobile computer to allow accurate localization. The mobile computer **104** navigates industrial vehicles accurately using dynamically placed pre-positioned objects as the only available landmarks.

In some embodiments, the mobile computer **104** is configured to determine a vehicle pose at start up, which requires localization with respect to a reference map without any knowledge of a previous vehicle pose. The reference map provides sufficient a-priori map data in a global coordinate system. Once the mobile computer **104** determines that a vehicle pose of the industrial vehicle **102** is unknown (e.g., when the automation system has just been started), the mobile computer **104** performs a search to determine the most likely position of the industrial vehicle **102** using one of a number of methods which include examining the environment for a unique configuration of features or purposefully placed navigation markers **116**. In examining the environment, various measurements are extracted from sensor data (for example, angles, lengths, radii, and the like), and are processed to determine current observable features which are compared with known features to provide an initial vehicle pose. Based on the vehicle pose, the mobile computer **104** subsequently determines a path for completing a task within the physical environment **100**.

An alternative method in accordance with embodiments of the invention involves where the mobile computer receives a position from an external source, e.g., a user interface or a low precision localization system such as that disclosed by US Patent Publ. No. 2011/0148714 A1 entitled Near Field Electromagentic Location System and Method. As an example of another alternative method, an object used as a landmark may be uniquely identifiable through the use of barcodes, RFID, specific shape, or any other unique feature that can be sensed by the sensors of an industrial vehicle and used as a reference point to remove ambiguity from the surrounding observable features being compared with known previously mapped features.

FIG. **2** illustrates a perspective view of the forklift **200** for facilitating automation of various tasks within a physical environment according to one or more embodiments of the present invention.

The forklift **200** (i.e., a lift truck, a high/low, a stacker-truck, trailer loader, sideloader, a fork hoist, and the like) is a powered industrial truck having various load capacities and used to lift and transport various objects. In some embodiments, the forklift **200** is configured to move one or more pallets (e.g., the pallets **112** of FIG. **1**) of units (e.g., the units **114** of FIG. **1**) along paths within the physical environment (e.g., the physical environment **100** of FIG. **1**). The paths may be pre-defined or dynamically computed as tasks are received. The forklift **200** may travel inside a storage bay that is multiple pallet positions deep to place or retrieve a pallet. Oftentimes, the forklift **200** is guided into the storage bay and places the pallet on cantilevered arms or rails.

The forklift **200** typically includes two or more forks (i.e., skids or tines) for lifting and carrying units within the physical environment. Alternatively, instead of the two or more forks, the forklift **200** may include one or more metal poles (not pictured) in order to lift certain units (e.g., carpet rolls, metal coils and/or the like). In one embodiment, the forklift **200** includes hydraulics-powered, telescopic forks that permit two or more pallets to be placed behind each other without an aisle between these pallets.

The forklift **200** may further include various mechanical, hydraulic and/or electrically operated actuators according to one or more embodiments. In some embodiments, the forklift **200** includes one or more hydraulic actuator (not labeled) that permit lateral and/or rotational movement of two or more forks. In one embodiment, the forklift **200** includes a hydraulic actuator (not labeled) for moving the forks together and apart. In another embodiment, the forklift **200** includes a mechanical or hydraulic component for squeezing a unit (e.g., barrels, kegs, paper rolls and/or the like) to be transported.

The forklift **200** may be coupled with the mobile computer **104**, which includes software modules for operating the forklift **200** in accordance with one or more tasks. The forklift **200** is also coupled with an array comprising various sensor devices (for example, the sensor array **108** of FIG. **1**), which transmits sensor data (for example, image data, video data, range map data and/or three-dimensional graph data) to the mobile computer **104** for extracting observed features from environmental landmarks. These devices may be mounted to the forklift **200** at any exterior and/or interior position or mounted at known locations around the physical environment **100**. Exemplary embodiments of the forklift **200** typically include a camera **202** and/or a two-dimensional laser scanner **204** attached to each side and/or an encoder **206** attached to each wheel **208**. In other embodiments, the forklift **200** includes only the planar laser scanner **204** and the encoder **206**. These encoders determine motion data related to vehicle movement. In some embodiments, a number of sensor devices (for example, laser scanners, laser range finders, encoders, pressure transducers and/or the like) as well as their position on the forklift **200** are vehicle dependent, and the position at which these sensors are mounted affects the processing of the measurement data. For example, by ensuring that all of the laser scanners are placed at a measurable position, the sensor array **108** may process the laser scan data and transpose it to a center point for the forklift **200**. Furthermore, the sensor array **108** may combine multiple laser scans into a single virtual laser scan, which may be used by various software modules to control the forklift **200**.

In some embodiments, sensors are mounted at fixed positions in the environment (e.g., the environment **100** of FIG. **1**), referred to as external sensors, where the rich data set available from such sensors would enhance automated operations. Such external sensors may include laser scanners or cameras, and the like. External sensors may also include a limited set transponders and/or other active or passive means by which an automated vehicle could obtain an approximate position to seed a localization function.

FIG. **3** is a structural block diagram of a system **300** for providing accurate localization for an industrial vehicle according to one or more embodiments. In some embodiments, the system **300** includes the mobile computer **104**, the central computer **106** and the sensor array **108** in which each component is coupled to each other through a network **302**.

The mobile computer **104** is a type of computing device (e.g., a laptop, a desktop, a Personal Desk Assistant (PDA) and the like) that comprises a central processing unit (CPU) **304**, various support circuits **306** and a memory **308**. The CPU **304** may comprise one or more commercially available microprocessors or microcontrollers that facilitate data processing and storage. Various support circuits **306** facilitate operation of the CPU **304** and may include clock circuits, buses, power supplies, input/output circuits and/or the like. The memory **308** includes a read only memory, random access memory, disk drive storage, optical storage, removable storage, and the like. The memory **308** includes various data, such as map data **310**, pose measurement data **316**, and pose prediction data **318**. The map data includes: sub-area maps **352**, object feature information **312**, landmark information **314**, placed object model data **342**, and an overview map **350**. The memory **308** includes various software packages, such as an environment based navigation module **320**.

The central computer **106** is a type of computing device (e.g., a laptop computer, a desktop computer, a Personal Desk Assistant (PDA) and the like) that comprises a central processing unit (CPU) **322**; various support circuits **324** and a memory **326**. The CPU **322** may comprise one or more commercially available microprocessors or microcontrollers that facilitate data processing and storage. Various support circuits **324** facilitate operation of the CPU **322** and may include clock circuits, buses, power supplies, input/output circuits and/or the like. The memory **326** includes a read only memory, random access memory, disk drive storage, optical storage, removable storage, and the like. The memory **326** includes various software packages, such as a map manager **328**, as well as various data, such as a task **330**, a complete map database **340**, and placed object database **346**.

The network **302** comprises a communication system that connects computing devices by wire, cable, fiber optic, and/or wireless links facilitated by various types of well-known network elements, such as hubs, switches, routers, and the like. The network **302** may employ various well-known protocols to communicate information amongst the network resources. For example, the network **302** may be part of the Internet or intranet using various communications infrastructure such as Ethernet, WiFi, WiMax, General Packet Radio Service (GPRS), and the like.

The sensor array **108** is communicably coupled to the mobile computer **104**, which is attached to an automated vehicle, such as a forklift (e.g., the forklift **200** of FIG. **2**). The sensor array **108** includes a plurality of devices **332** for monitoring a physical environment and capturing various data, which is stored by the mobile computer **104** and/or the central computer **106**. In some embodiments, the sensor array **108** may include any combination of one or more laser scanners and/or one or more cameras. In some embodiments, the plurality of devices **332** may be mounted to the automated industrial vehicle. For example, a laser scanner and a camera may be attached to a lift carriage at a position above or, alternatively, below the forks.

In some embodiments, the map data **310** is partitioned into plurality of sub-area maps **352** where sub areas may overlap or may be distinct. Each sub-area map is comprised of a number of landmarks where landmarks may be static or dynamic. Landmarks may be included into the maps associated with one or more sub-areas as well as an overview map. Each landmark has associated features which are observable by one or more sensors. In some embodiments some landmarks may be associated with plurality of dynamically placed pre-positioned objects or even predominantly pre-positioned objects. The map data **310** may include a vector of known features. The feature information **312** defines features (for example, curves, lines and/or the like) associated with one or more landmarks. In some embodiments, the map data **310** indicates locations of objects (for example, dynamically placed pre-positioned objects) throughout the physical environment.

In some embodiments dynamic landmarks are associated with dynamically placed pre-positioned objects such as a pallet (e.g. the pallet **112** of FIG. **1**) loaded with items (e.g. the items **114** of FIG. **1**). The object has a known geometry defined as the placed object model data **342** which describes a set of feature information **312** for said object that may be used by the environment based navigation module **320** for vehicle localization. Thus when a task **330** is executed by the industrial vehicle, which results in a object being placed in the physical environment, the industrial vehicle can determine the pose of the placed object from the pose prediction data **318** and the location of the object on the forks of the industrial vehicle. The environment based navigation module **320** may then add landmark information **314** to the map data **310** creating the landmark with the features from the placed object model data **342**, the landmark pose from the location at which the object was placed, and the object pose uncertainty from the pose prediction data **318**. These placed objects, when added to a map **310**, may then provide landmarks with observable features, which when used allows an industrial vehicle to be accurately navigated.

In some embodiments, the placed object may be uniquely identifiable through the use of barcodes, RFID, specific shape, or any other unique feature that can be sensed by the sensors of an industrial vehicle. The map data may then be updated to also include the unique attribute of the placed object. Once the object is identified, placed object data **342** may be accessed to inform the mobile computer **104** the nature of the placed object, i.e., the pose of the object. If the object data for the identified object is not locally stored as placed object data **342**, the mobile computer can request the information from the central computer **106**. The central computer **106** maintains the placed object database **346** and complete map **340** containing information regarding all pre-positioned objects. The pre-positioned object data **342** may be used by the environment based navigation module **320** to develop a navigational position as further described below.

In some embodiments, an industrial vehicle does not retain its position when the computer **104** is unpowered. In this case, the industrial vehicle may not know a current vehicle pose when the computer **104** is powered on. The industrial vehicle may identify one or more unique pre-positioned objects through the use of barcodes, RFID, specific shape, or any other unique feature that can be sensed by the sensors of an industrial vehicle. The unique pre-positioned object is used to seed the initial vehicle pose. The environment based navigation module may then retrieve other features from the map and use these for localization.

In some embodiments, the pose measurement data **316** includes an aggregation of data transmitted by the plurality of devices **332**. Such data represents one or more observed features of objects within the environment. In one embodiment, the one or more cameras transmit image data and/or video data of the physical environment that are relative to a vehicle. In another embodiment, the one or more laser scanners (e.g., two-dimensional laser scanners) analyze objects within the physical environment and capture data relating to various physical attributes, such as size and shape. The captured data can then be compared with dimensional object models. The laser scanner creates a point cloud of geometric samples on the surface of the subject. These points can then be used to extract the observed features of the subject. The camera records image information which may be processed to extract features including lines, patterns, and color, and the like.

In some embodiments, the pose prediction data **318** includes an estimate of vehicle position and/or orientation of which the present disclosure may refer to as the vehicle pose prediction. The environment based navigation module **320** produces updated estimates using a prior vehicle pose in addition to the sensor measurements to indicate amount of movement (for example, inertial measurement unit (IMU) or odometer). The environment based navigation module **320** may also use a process filter to estimate uncertainty and/or noise for an upcoming vehicle pose prediction and update steps. Using odometry data, for example, the environment based navigation module **320** computes the distance traveled by the industrial vehicle from a prior vehicle pose, along with uncertainty of the pose given by the noise model of the odometry device. After subsequently referencing a map of the physical environment containing object landmarks with associated observable features, and comparing actual observed features from sensory data (for example, laser range sensor, camera, and the like) with the said map, the environment based navigation module **320** determines a more accurate estimate of a current vehicle pose and updates the pose uncertainty.

The environment based navigation module **320** includes processor-executable instructions for localizing the industrial vehicle **102** using unique landmarks according to some embodiments. In some embodiments, the environment based navigation module **320** may use predominantly dynamically placed pre-positioned objects to develop a current vehicle pose. The use of a process filter to develop a vehicle pose is described in U.S. patent application Ser. No. 13/116,600, filed May 26, 2011. In these embodiments, the process filter (e.g., a kalman filter or the like) can model both the uncertainty in the pose of a pre-positioned object and the uncertainty in a sensor measurement of the pre-positioned object features and develop a reliable pose prediction **318**, despite the increased uncertainty. In order to use pre-positioned objects as landmarks for navigation, in one embodiment pre-positioned objects are added to and removed from the map data **310** as landmark information **314** as the vehicle executes tasks **330**, such as picking or placing pallets of product, and the like. The pre-positioned object data may be shared between vehicles. In another embodiment, pre-positioned objects are added to and removed from the map data **310** in response to action external to a vehicle such as an update from a user interface, warehouse management system, factory control system and/or the like. The update changes the occupancy of a pre-defined slot to include or exclude a pre-positioned object on the map with an associated position and uncertainty.

FIG. **4** is a functional block diagram of a system **400** for providing accurate localization for an industrial vehicle according to one or more embodiments. The system **400** includes the mobile computer **104**, which couples to an industrial vehicle, such as a forklift, as well as the sensor array **108**. Various software modules within the mobile computer **104** collectively form an environment-based navigation module (e.g., the environment based navigation module **320** of FIG. **3**).

The mobile computer **104** includes various software modules (i.e., components) for performing navigational functions, such as a localization module **402**, a mapping module **404**, a correction module **408**, and a vehicle controller **410**. The mobile computer **104** provides accurate localization for the industrial vehicle and updates map data **406** with dynamically placed pre-positioned object landmarks. The localization module **402** may also include various components, such as a filter **414** and a feature extraction module **416**. The map module **404** may include various data, such as static features **424** (such as features that do not change on the map, such as features created by walls and fixed racking, and the like) and dynamic features **422** (features that may change on the map, such as features created by placing pallets or pre-positioned objects on the map, and the like). The map module **404** may also include various components, such as a feature selection module **420** and pre-positioned object management **426**.

In some embodiments, the localization module **402** processes corrected sensor data from the correction module and operates on this data to estimate a vehicle pose. The filter **414** updates the vehicle pose prediction to account for an incorrect estimation and/or observation uncertainty. The filter **414** determines the vehicle pose **418** and may instruct the mapping module **404** to update the map data **406**. The vehicle pose **418**, which is modeled by the filter **414**, refers to a current vehicle position and orientation. The localization module **402** communicates data associated with the vehicle pose **418** to the mapping module **404** while also communicating such data to the vehicle controller **410**. Based on the vehicle pose, the vehicle controller **410** navigates the industrial vehicle to a destination.

In addition to the filter **414** for calculating the vehicle pose **418**, the localization module **402** also includes the feature extraction module **416** for extracting known standard features from the corrected sensor data. The filter **414** compares the extracted features with the dynamic features **422** and static features in the map module **404** to determine a vehicle pose.

The localization module **414** may use the vehicle pose **418** and the mapping module **404** to reduce a number of features to examine by eliminating invisible features or features at a defined distance from the current vehicle position. The feature selection module **420** manages addition and modification of the dynamic features **422** to the map data **406**. Some of these objects are dynamically placed pre-positioned objects for which the pre-positioned object management module is involved. When the industrial vehicle is executing a task to place a product in the warehouse (e.g., the environment **100** of FIG. **1**), the vehicle controller **410** will communicate with the localization module **402** to indicate that a new dynamically placed object is to be created on the map. Information provided to the localization module **402** will include the pose of the object relative to the vehicle center and the uncertainty in that measurement and may include the unique object identity. The localization module **402** will examine the current vehicle pose and uncertainty (for example, the pose prediction data **318** of FIG. **3**) and will request that the pre-positioned object management module **426** add one or more new features to the map. The pre-positioned object management module **426** will calculate the pose of the object and the pose uncertainty of the object and will create a landmark (for example, the landmark information **314** of FIG. **3**) and a reference set of features **422** for the object by referencing a model of the placed object (for example, the placed object data **342** of FIG. **3**).

It is appreciated that the system **400** may employ several computing devices to perform environment based navigation. Any of the software modules within the computing device **104** may be deployed on different or multiple physical hardware components, such as other computing devices. The mapping module **404**, for instance, may be executed on a server computer (for example, the central computer **102** of FIG. **1**) over a network (for example, the network **302** of FIG. **3**) to connect with multiple mobile computing devices for the purpose of sharing and updating the map data **406** with a current vehicle pose.

In some embodiments, the correction module **408** processes sensor input messages from disparate data sources, such as the sensor array **108**, having different sample/publish rates as well as different (internal) system delays. The correction module **408** examines each message separately in order to preserve the consistency of each observation. Such an examination may be performed in place of fusing the sensor data to avoid any dead reckoning errors. Notice that with different sampling periods and different system delays, the order at which the sensor data is acquired is not the same as the order at which the sensor input messages eventually became available to the computing device **104**.

FIG. **5** is a schematic illustration of an environment map **500** for a physical environment including a plurality of dynamically placed pre-positioned objects forming the majority of available landmarks according to one or more embodiments of the invention. The map **500** is partitioned into a sub-area **502**, a sub-area **504**, a sub-area **506**, and a sub-area **508**. Sub-area maps may overlap or be non-contiguous. The map **500** depicts both static landmarks such as the wall **516**, the navigation beacon **514**, racking protectors **510** as well as the racking **512**. The map **500** also depicts a plurality of pre-positioned dynamic objects including the objects **522** currently invisible to the industrial vehicle **530** which may be of the same type as vehicle **102** in FIG. **1**, as they are either outside the current sub-map **502** or outside the sensor range **519**. The map **500** also depicts the dynamically placed pre-positioned objects **520** visible to the industrial vehicle **530**. The industrial vehicle **530** is located in the position shown with sensor range **519** and is carrying object **521**.

The industrial vehicle **530** is dependent on the dynamically placed pre-positioned objects **520** to develop a pose that will allow it to place the product **521** in the position specified by the current task (for example, the task **330** of FIG. **3**) as no static features that are currently visible (such as the racking legs **512**) pre-positioned objects **520** are used to provide an accurate localization pose. Once the industrial vehicle **530** completes placing the product **521**, this product may be added to the map as a new dynamically placed pre-positioned object as described above. Once the placed object **521** is added to the map with associated features and uncertainty it may be used for localization. The pre-positioned object model information together with its pose provides observable features from all sides of the object, thus the object may be used as a navigational reference from directions which have not previously been observed. An industrial vehicle **530** or a second industrial vehicle may remove a pre-positioned object from the global map. Once the pre-positioned object is removed from the global map, the individual vehicles local maps may be updated and the pre-positioned object is not longer used as a navigational reference.

A second industrial vehicle **531**, which may be of the same type as vehicle **102** in FIG. **1**, may be dependent on the dynamically placed pre-positioned objects **522** and static landmarks **512** to develop a pose. Objects **522** are placed in slots, which is a description of the approximate location of a pallet **112** which may hold a plurality of units **114**. Pre-positioned objects may be placed into or removed from the slot by an automated industrial vehicle, a manual industrial vehicle, a convey system, or the like. In the event that the occupancy slot becomes occupied, a pre-positioned object is created on the map. The map data is provided to the industrial vehicle to be used as a navigational reference with an associated uncertainty. Similarly, if a slot becomes empty, the pre-positioned object is removed from the map. The map data is provided to the vehicle and the pre-positioned object of the individual slot is removed from the map as a navigational reference.

FIG. **6** is a flow diagram of a method **600** for designating a pre-positioned object as a unique landmark for facilitating localization according to one or more embodiments. In some embodiments, the method may include placing an object in the environment, designating said object as a dynamically placed pre-positioned object, storing the location of said object as a landmark on a map, and using said landmarks to navigate an industrial vehicle. The method includes identifying at least one dynamically placed object within a physical environment, wherein the dynamically placed object corresponds with a mapped area of the physical environment, and determining industrial vehicle pose by an environment base navigation module in response to matching feature information from the vehicle's sensors that correspond to the features of at least one dynamically placed object. In some embodiments, an environment based navigation module (e.g., the environment based navigation module **320** of FIG. **3**) may perform each step of the method **600**.

In some embodiments, some steps may be omitted or performed by other modules. The environment based navigation module is stored within a mobile computer (e.g., the mobile computer **104** of FIG. **1**) that is operably coupled to an industrial vehicle (e.g., the industrial vehicle **102** of FIG. **1**). A central computer (e.g., the central computer **106** of FIG. **1**) includes a map manager (e.g., the map manager **328** of FIG. **3**) for communicating with the industrial vehicle as well as one or more second industrial vehicles. When performing a task (e.g., the task **330** of FIG. **3**), a task manager communicates instructions for executing the task. For example, the manager may instruct the environment based navigation module to navigate the industrial vehicle along a particular path while carrying an object (e.g., a pallet **112** containing items **114** of FIG. **1**) to be placed in the environment. Turning to FIG. **6**, the method **600** starts at step **602** and proceeds to step **604**.

At step **604**, the method **600** operates the industrial vehicle according to one or more tasks. In some embodiments, the method **600** localizes and navigates the industrial vehicle about the physical environment while completing tasks. Some tasks require the industrial vehicle to load and unload objects, such as product items (e.g., the plurality of units **114** of FIG. **1**) or pallets (e.g., the plurality of pallets **112** of FIG. **1**), at assigned locations that are referred to as slots. As explained further below, an object, once unloaded, may be designated a unique landmark for the purpose of facilitating localization.

At step **606**, the method **600** determines whether the current task involves placing an object and whether that objects is to be considered a pre-positioned object to be added to map data. If there is a pre-positioned object the method **600** proceeds to step **610**. If, on the other hand, there is no pre-positioned object to add to the map data, the method **600** proceeds back to the start. At step **610**, the method **600** uses the model information to select the appropriate feature information (e.g., the object feature information **312** of FIG. **3**) associated with the pre-positioned object that is being placed. In any environment, there are many objects to be handled by an industrial vehicle and each type of object may have different feature information. Furthermore, while the industrial vehicle is placing the object, the sensor(s) have a limited view of the object, however the map may contain a complete description of the object so that another industrial vehicle approaching the pre-positioned object from a different direction can identify the sensor object as the current pre-positioned object.

At step **614**, the method **600** determines the object pose and uncertainty relative to the vehicle's current pose and uncertainty. In some embodiments, the pose of the object will be measured using vehicle sensors (e.g., the sensor array **108** of FIG. **1**). This sensor measurement will be subject to a sensor data uncertainty and commissioned sensor position on the vehicle uncertainty that are characteristic to the sensor and mounting mechanism. In other embodiments, an object may be accurately positioned on a vehicle attachment, e.g., by clamps or on the forks, and a commissioned measurement of the attachment pose relative to the vehicle origin may be used.

At step **616**, the method **600** updates the map data (e.g., the map data **310** of FIG. **3**) with the pre-positioned object landmark and feature information. The new dynamic landmark (e.g., the landmark information **314** of FIG. **3**) will be generated in the map and the landmark will include dynamic features (e.g., the object feature information **312** of FIG. **3**) observable from one or more sides of the new landmark. The new landmark pose will be relative to the vehicle pose in a global reference frame and translated to the landmark center according to the placed object model (e.g., the placed object data **342** of FIG. **3**). In other embodiments, the map may already include invisible dynamic objects generated from slot locations according to parametric data derived from the rack dimensions or according to a site defined storage rule for block storage areas and updating the map involves making the invisible object visible and indicating an uncertainty associated with the position of the real object relative to the generated pose.

At step **618**, the method **600** communicates the updated map data to, for example, one or more second industrial vehicles. At step **620**, the method **600** determines a vehicle pose using the updated map data. The method **600** proceeds to step **624**. At step **624**, the method **600** ends.

It is appreciated that method **600** can also be used to remove a pre-positioned object landmark from the map. At step **626** the method determines if the task involves picking an object. If so, the method accesses the object data at step **628**, removes the pre-positioned object, and updates the map at step **616**. The update map is then communicated to the vehicles at step **618**.

While the foregoing is directed to embodiments of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

The invention claimed is:

1. A method of using dynamically placed pre-positioned objects as landmarks to operate an industrial vehicle, the method comprising:

transporting an object along a path within a physical environment and placing the object at a location within the physical environment such that the placed object becomes a dynamically placed pre-positioned object in the physical environment;

determining a pose of the dynamically placed pre-positioned object based at least in part on (i) vehicle pose prediction data stored on a central computer or a mobile computer coupled to the industrial vehicle and (ii) a location of the placed object relative to a lift carriage of the industrial vehicle;

updating a map of the physical environment by using the determined pose and adding placed object data representing the dynamically placed pre-positioned object to the map of the physical environment to create updated map data such that the placed object, when added to the map, serves as a landmark with observable features and can be used in navigation of an industrial vehicle with access to the updated map data;

storing the updated map data on a mobile computer attached to the industrial vehicle or on a central computer coupled to the industrial vehicle via a network; and

operating the industrial vehicle based on a navigational position determined from sensor data and the updated map data by navigating the industrial vehicle along a path within the physical environment.

2. The method of claim **1** further comprising:

creating a landmark based at least in part on the placed object data, wherein the placed object data comprises features from the placed object, a landmark pose representing the location at which the object was placed, and an object pose uncertainty from the vehicle pose prediction data;

adding the landmark to the updated map data; and

operating the industrial vehicle based on a navigational position determined from updated map data including the landmark.

3. The method of claim **2** wherein:

the placed object comprises a unique identifier; and

the method comprises utilizing a sensor on the industrial vehicle to sense the unique identifier.

4. The method of claim **3** wherein the placed object data is stored on the central computer or the mobile computer with data representing the unique identifier.

5. The method of claim **1** wherein:

object pose prediction data is stored on the mobile computer or the central computer; and

the industrial vehicle comprises a sensor for determining the location of an object to be placed relative to a lift carriage of the industrial vehicle.

6. The method of claim **1** wherein the object is transported and placed using an industrial vehicle, an automated industrial vehicle, or a conveyer system.

7. The method of claim **1** wherein:

operation of the industrial vehicle comprises a transition from an unpowered state to a powered state where current vehicle pose is unknown; and

the industrial vehicle is subsequently operated by determining current vehicle pose from the updated map data and navigating the industrial vehicle along the path within the physical environment.

8. The method of claim **1** wherein the dynamically placed pre-positioned object comprises a pallet loaded with items.

9. The method of claim **1** wherein the dynamically placed pre-positioned object has a known geometry, and the method comprises:

defining the known geometry as placed object model data that describes a set of feature information for the dynamically placed pre-positioned object; and

operating the industrial vehicle based on vehicle localization using the placed object model data.

10. The method of claim **9** wherein:

the dynamically placed pre-positioned object comprises a pallet and items located on the pallet; and

the updated map data comprises a model of the pallet and the items located on the pallet.

11. The method of claim **1**, wherein:

the updated map data comprises invisible dynamic objects generated from slot locations according to parametric data derived from warehouse rack dimensions or according to a site defined storage rule for block storage areas; and

the method comprises updating the map to make the invisible object visible.

12. The method of claim **1** wherein the placed object data representing the dynamically placed pre-positioned object serves as a landmark comprising features that are observable from more than one side of the landmark.

13. The method of claim **1** wherein the placed object data is at least partially derived from a sensor attached to the industrial vehicle.

14. The method of claim **1** wherein the sensor data from which the navigational position is determined comprises image data, laser range data, ultrasonic range data, pressure transducer data, encoder data, or combinations thereof.

15. The method of claim **1** wherein the placed object data forms a majority of landmarks comprised in the updated map data.

16. The method of claim **1** wherein the current vehicle pose is determined by referring to landmark data predominantly comprising placed object data.

17. The method of claim **1** wherein the current vehicle pose is determined by referring to landmark data consisting entirely of placed object data.

18. The method of claim **1** wherein:

the step of operating the industrial vehicle based on the navigational position determined from the sensor data and the updated map data comprises one or more automated operations executed with the assistance of a central computer or a mobile computer attached to the industrial vehicle; and

the automated operations are selected from a vehicle navigating operation, a vehicle status alert display, or combinations thereof.

19. A computer attached to an industrial vehicle or coupled to an industrial vehicle via a network, the computer comprising a navigation module for operating the industrial vehicle based on a navigational position determined from sensor data and updated map data, wherein the computer enables the use of dynamically placed pre-positioned objects as landmarks to operate an industrial vehicle according to the method of claim **1**.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,056,754 B2
APPLICATION NO. : 13/672391
DATED : June 16, 2015
INVENTOR(S) : Lisa Wong et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Specification

Col. 6, Line 20,
"placed safety in the positions required by one or more tasks." should read
--placed safely in the positions required by one or more tasks.--; and

Col. 14, Line 23,
"rent task involves placing an object and whether that objects" should read
--rent task involves placing an object and whether that object--.

Signed and Sealed this
Twenty-ninth Day of March, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office